Case Report Rapport de cas

An outbreak of bovine tuberculosis in an intensively managed conservation herd of wild bison in the Northwest Territories

Chelsea G. Himsworth, Brett T. Elkin, John S. Nishi, Aleksija S. Neimanis, Gary A. Wobeser, Claude Turcotte, Fredrick A. Leighton

Abstract — An outbreak of bovine tuberculosis was detected in the Hook Lake Wood Bison Recovery Project captive-breeding herd in March 2005. This study investigates the most likely source of *Mycobacterium bovis* and identifies difficulties associated with salvaging tuberculosis-free animals from an endemically infected herd.

Résumé — Éclosion de tuberculose bovine dans un troupeau de conservation de bisons sauvages à gestion intensive dans les Territoires du Nord-Ouest. En mars 2005, une éclosion de tuberculose bovine a été détectée parmi le troupeau d'élevage en captivité du Projet de rétablissement du bison des bois du lac Hook. Cette étude examine la source la plus probable de *Mycobacterium bovis* et identifie les difficultés associées à la récupération des animaux libres de tuberculose d'un troupeau atteint d'une infection endémique.

(Traduit par Isabelle Vallières)

Can Vet J 2010;51:593–597

It is estimated that there are currently ~4600 free-ranging bison in and around Wood Buffalo National Park (WBNP) (R. Kindopp, Ecosystem Scientist, Wood Buffalo National Park, personal communication), an area that includes parts of the southeastern Northwest Territories (NWT) and northeastern Alberta. This metapopulation is endemically infected with *Mycobacterium bovis* and *Brucella abortus,* disease agents that were likely introduced through translocation of 6673 plains bison *(Bison bison bison)* from Buffalo National Park near Wainwright, Alberta to WBNP in the 1920's (1–3).

The presence of bovine tuberculosis and brucellosis in free-ranging bison in and around WBNP poses a variety of risks to healthy wild wood bison *(Bison bison athabascae)* populations, to domestic cattle and bison, and to local aboriginal communities that harvest bison from these herds. For this reason, in 1996, the Hook Lake Wood Bison Recovery Project (HLWBRP) was initiated cooperatively between the Government of the NWT, the Deninu Kue' First Nation, and the Aboriginal Wildlife Harvester's Committee (1,2). The goals of the project included the establishment of a genetically diverse, tuberculosis- and brucellosis-free captive bison herd, followed by the gradual elimination of infected wild herds through hunting and range isolation, and, ultimately, the re-introduction of disease-free bison back into the Slave River Lowlands (SRL) northeast of WBNP (1,2,4–6). The project involved a bison population in the SRL, which has traditionally been harvested by the community of Fort Resolution and managed by the Government of the NWT.

Between 1996 and 1998, a total of 62 newborn bison calves from bovine tuberculosis- and brucellosis-infected wild herds in the SRL were captured in order to provide foundation stock for the captive breeding program (1,5). The animals were determined to have no antibodies against *Brucella* through use of the card test (6) (at the time, there was no available field test for tuberculosis that would require only a single capture). These bison were subsequently transported to an isolation facility near Fort Resolution, NWT, where they were hand reared and given extensive antimicrobial prophylaxis to control undetected

Department of Veterinary Pathology, Western College of Veterinary Medicine, 52 Campus Drive, Saskatoon, Saskatchewan S7N 5B4 (Himsworth); Wildlife Division, Government of the Northwest Territories Environmental and Natural Resources, 5102 50th Avenue, Yellowknife, Northwest Territories X1A 3S8 (Elkin, Nishi); Canadian Cooperative Wildlife Health Center, Department of Veterinary Pathology, Western College of Veterinary Medicine, 52 Campus Drive, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5B4 (Neimanis, Wobeser, Leighton); Canadian Food Inspection Agency, Mycobacterial Diseases Center of Expertise, Ottawa Laboratory Fallowfield, 3851 Fallowfield Road, Ottawa, Ontario K2H 8P9 (Turcotte).

Address all correspondence to Dr. Chelsea G. Himsworth; e-mail: chelsea.himsworth@usask.ca

Dr. Nishi's current address is EcoBorealis Consulting Inc., Box 39, Site 2, RR1, Millarville, Alberta T0L 1K0.

Dr. Neimanis' current address is Department of Pathology and Wildlife Diseases, National Veterinary Institute, 751 89 Uppsala, Sweden.

M. bovis or *B. abortus* infection (1). When these founder animals reached sexual maturity, they were used for breeding in order to produce captive-born and, hopefully, disease-free progeny that were genetically representative of the founders. The project's salvage protocol called for the eventual culling and extensive disease testing of all wild-caught founders to assess their disease status and the likelihood of disease exposure in the captive-born cohort. This captive-bred herd was to serve as stock for re-introduction of tuberculosis- and brucellosis-free bison into the SRL, and all wild-caught animals were slated for slaughter (rather then release) at the end of the project.

The bison were maintained in several discreet, physically separated groups for the purposes of breeding management. Each animal in the herd was tested, on average, twice annually for brucellosis (using the Buffered Plate Antigen Test, Standard Tube Agglutination Test, Compliment Fixation Test, Competitive Enzyme-Linked Immunosorbant Assay and Fluorescent Polarization Assay) (6–8), and tuberculosis [using the caudal fold test (9) and a Fluorescent Polarization Assay that was not validated for use in bison (10)] (1). Animals were culled periodically to maintain herd size and manage population health and genetic diversity, and all culled animals underwent complete necropsy and postmortem screening for tuberculosis and brucellosis using histopathology and culture. In 2003, a risk assessment was conducted by the Canadian Food Inspection Agency (CFIA), and, based on the tuberculosis and brucellosis surveillance regimens that were in place, it was estimated that the 95% probability of 1 infected bison being present was < 0.0003 and < 0.0002 for tuberculosis and brucellosis, respectively (11).

Case description

In March 2005, 9 y into the project, a 2.5-year-old captive-born bull (identification number O28) selected for routine slaughter was noted on postmortem examination to have multiple abscessed lymph nodes. Tissues were sent to the CFIA Mycobacterial Diseases Center of Expertise (MDCE), Ottawa, Ontario, for culture, and *M. bovis* was isolated (12). Spoligotyping of the isolate revealed that it was identical to the *M. bovis* strain found in bison in and around WBNP (12). At the time of detection there were 119 animals in the herd, and a series of ante- and postmortem tuberculosis tests were performed to assess the prevalence and distribution of the disease within the herd. Although there was a concerted effort to salvage a group of 20 physically isolated, captive-born pregnant females that appeared to be tuberculosis-free, financial and logistic constraints ultimately resulted in complete herd depopulation by the end of March 2006. In order to detect any other cases of bovine tuberculosis, all depopulated animals underwent complete necropsy, and 2 specified sets of tissues, including multiple lymph nodes, lung, liver, kidney, spleen, reproductive organs, and mammary gland, were collected, 1 of which was fixed in 10% neutral-buffered formalin. Both sets were sent to the CFIA MCDE to be analyzed using a standardized tuberculosis detection protocol that consisted of light microscopy (using formalin-fixed tissues), including Ziehl-Neelsen staining for acid fast organisms, and culture (using fresh tissues).

Table 1. Summary of the results of histopathology, acid-fast staining, and bacterial culture from animals necropsied during an outbreak of *M. bovis* in a captive herd of wood bison

				Location of lesions consistent with tuberculosis on histology								
Animal ID	Sex	Age (y)	Gross lesions consistent with tuberculosis (yes/no)	Cranial lymph node(s)	Thoracic lymph node(s)	Abdominal lymph node(s)	Superficial lymph node(s)	Unidentified lymph node(s)[d]	Lung	Liver	Peri-umbilical tissue	Acid-fast bacteria in one or more lesions[e]	*M. bovis* culture
Y36[a]	F	9.2	Yes	X[c]	—	—	—	—	—	—	—	No	Positive
Y45[a]	F	9.2	Yes	—	X	—	X	—	X	—	X	Yes	Positive
Y49[a]	F	9.4	Yes	—	—	—	—	—	—	X	—	No	Negative
Y124[a]	M	7.8	No	—	—	—	—	—	—	X	—	No	Negative
O13[b]	M	4.9	Yes	X	—	—	—	—	—	—	—	Yes	Positive
O28[b]	M	2.8	Yes	X	X	X	X	—	X	X	—	Yes	Positive
O29[b]	M	3.3	Yes	—	—	—	—	X	—	—	—	Yes	Positive
O30[b]	M	3.2	Yes	X	—	—	—	—	—	—	—	No	Positive
O45[b]	M	3.4	Yes	X	—	—	—	—	—	—	—	Yes	Positive
O47[b]	M	3.5	No	—	—	—	—	—	—	—	—	n/a[f]	Positive
O68[b]	M	1.0	Yes	—	—	X	—	—	—	—	—	Yes	Positive
O69[b]	M	1.3	Yes	X	—	—	—	—	—	—	—	Yes	Positive
O70[b]	F	1.3	Yes	X	—	—	—	—	—	—	—	Yes	Positive
B21[b]	M	5.8	Yes	X	—	—	—	—	—	—	—	Yes	Positive

a = Founder (a bison that was captured from the wild as a calf); b = Captive-born; c = an "X" indicates a lesion was observed on histology whereas an "—" indicates that no lesions were observed on histological examination; d = Location of lymph node not recorded upon collection; e = Identified using Ziehl-Neelsen or Modified Fite's staining; f = Acid-fast staining not performed.

Selected fixed, paraffin-embedded tissues identified by the CFIA MCDE as having lesions potentially consistent with tuberculosis were later sent to the Western College of Veterinary Medicine (WCVM), Saskatoon, Saskatchewan, for further microscopic examination (using hematoxylin and eosin, as well as Fite's method for acid fast organisms).

For the purposes of this investigation, on microscopic examination, a lesion of any size and in any tissue was considered consistent with tuberculosis if it contained a core of necrotic material and/or degenerate neutrophils with or without areas of mineralization, and a mantle of epithelioid macrophages, multinucleated giant cells, lymphocytes, and plasma cells (13). A fibrous capsule or acid fast bacteria were additional supporting, but not obligate, criteria.

Histopathology was available for 43 animals, 13 of which had microscopic lesions consistent with tuberculosis, and *M. bovis* was isolated from 12 of 82 bison in which culture was performed (Table 1). All but 1 culture-positive bison had histopathological lesions consistent with tuberculosis. There was no evidence of *B. abortus* infection in any of the bison examined.

Discussion

The scope of the outbreak, in combination with its detection long after herd establishment and despite intensive antemortem tuberculosis testing, necessitated an investigation into how *M. bovis* was introduced and propagated within the herd. This investigation was particularly important given the experimental role of the HLWBRP in attempting to establish a protocol for salvage of disease-free bison from tuberculosis- and brucellosis-infected wild populations. The investigation included an analysis of the herd management records, ante- and postmortem tuberculosis testing data, interviews with the project managers, and a review of the relevant literature on *M. bovis* epidemiology in Canada and other areas of the world.

The *M. bovis* strain isolated from the outbreak was the same as that found in wild bison in and around WBNP, and was significantly different from *M. bovis* strains isolated elsewhere in Canada (12), indicating that the most likely source of the bacterium was from bison in and around WBNP. There are 4 potential ways in which *M. bovis* could have been transmitted from wild bison to the captive herd. These include unintentional transmission of the bacterium by humans, contamination of the isolation facility, introduction through wild animal vectors, and undetected infection in one of the founder animals.

Humans could have introduced *M. bovis* through use of contaminated clothing and equipment, or through direct transmission of disease from an infected human to a bison (14). Indirect transmission through fomites is unlikely as none of the equipment used in the facility had been exposed to potentially tuberculosis-contaminated environments (such as, the SRL), or used to handle wild bison or bison carcasses. Additionally, strict biosecurity procedures were in place, including personal and equipment movement restrictions, and the use of clean coveralls and boots within the facility. The number of people handling the bison was limited in order to reduce the risk of iatrogenic pathogen transmission, and, to confirm that people working at the isolation facility were not infected, a Mantoux tuberculin skin test, which can detect exposure to and infection with *M. bovis* in humans (15), was required. All personnel working at the facility were Mantoux test negative.

Another potential mechanism for *M. bovis* introduction might have been through environmental contamination of the facility with the bacterium prior to, or during, the project. The most likely source of contamination would have been through use of the land by infected wild bison prior to facility construction. However, no wild bison had been observed in the area of the isolation facility before its construction or during its operation, and the project site was not within the known range of any wild bison herd. In fact, the nearest known wild herd was a minimum of 50 km from the facility and across a major river, with very little suitable bison habitat between the 2 locations. Since the facility was in close proximity to Fort Resolution, adjacent to a residential neighborhood and a heavily used road, it is likely that the presence of wild bison in the area would have been detected. Historical use of the land by infected wild bison, however, cannot be ruled out, although research suggests that survival of *M. bovis* in the environment is most likely in the order of weeks or months, rather then years (16,17). For these reasons, environmental contamination of the isolation facility is considered unlikely.

A 3rd way in which tuberculosis could have been introduced is through contact between captive bison and other infected wild species. *Mycobacterium bovis* has a very wide host range (17,18), and many species of mammal and some birds are susceptible to infection under natural and/or experimental circumstances, although the epidemiology and range of susceptible species is highly variable among endemic areas. A study conducted in WBNP did not identify *M. bovis* infection in any of the 20 species studied, which included a number of rodents, carnivores, and ungulates other than bison (19). However, further investigation into the presence of *M. bovis* in species other than bison has been limited, thus the true range of susceptible species in the NWT is not well understood. Extrapolation of *M. bovis* ecology in other areas suggests that, within the SRL, the species that had the greatest potential to transmit tuberculosis from an infected wild bison herd to the captive breeding herd were white-tailed deer *(Odocoileus virginianus)* and *Mustela* spp. This is based on the ability of these species to become infected with *M. bovis* and to transmit the bacterium to cattle herds in other countries (18,20,21). White-tailed deer (WTD) are most likely to acquire infection, either from conspecifics or other species, under situations of unusually high animal density, such as when animals congregate around artificial food sources (20,22). This would be unlikely to occur in or around WBNP where WTD population densities are low, there is no agriculture, and feeding and baiting of wild ungulates is not practiced.

Among *Mustela* spp., ferrets *(Mustela furo)*, particularly in New Zealand, are the species in which *M. bovis* infection had been most commonly found, and they are thought to acquire infection primarily through scavenging on infected carcasses (23,24). Ferrets are not present in the area around the Slave River, although other *Mustela* spp., including the ermine *(Mustela erminea)* and least weasel *(Mustela nivalis)*, are abundant. *Mycobacterium bovis* infection has occasionally been

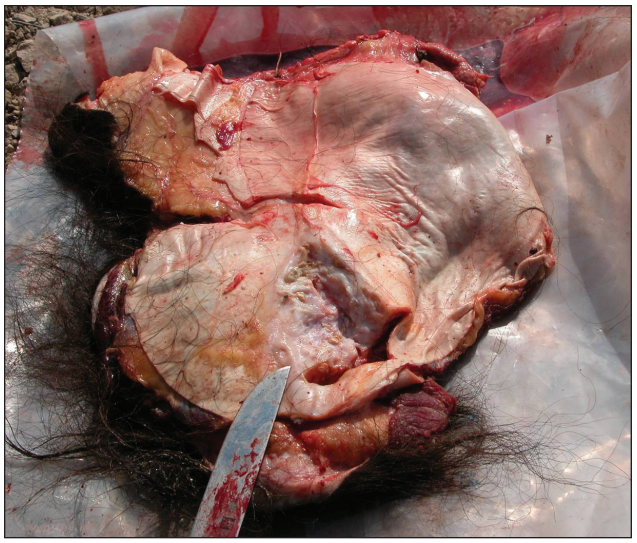

Figure 1. Section of abdominal wall from bison Y45 showing granulomatous subserosal inflammation in the peri-umbilical area.

diagnosed in ermine, also known as stoat, in New Zealand and the United Kingdom (25,26). There is some doubt, however, as to whether or not ermine and least weasel would have the opportunity to become infected with *M. bovis* in the NWT since they feed primarily on small vertebrates (27,28), and scavenging on dead bison, while possible, has not been reported.

Some mention should also be made of vole species, particularly those of the genus *Microtus,* as they are extremely susceptible to infection with *M. bovis,* may develop severe disease, and can shed the bacterium in their feces (29). The ability of voles to transmit the bacterium to other species, however, is unknown. *Mycobacterium bovis* was not detected in any of 55 voles that were trapped at the facility over the course of the project. Overall, the probability that tuberculosis could have been introduced to the captive bison through contact with other infected wildlife species is extremely low.

The most likely source for *M. bovis* introduction into the captive herd is through an infected founder animal (one that was infected in the wild prior to its capture as a calf). Of the founder animals culled during the outbreak, 4 had gross and histological lesions consistent with tuberculosis (Table 1). In 3 of these animals, lesions were limited: 1 animal had a single tuberculoid granuloma in a retropharyngeal lymph node, from which *M. bovis* was cultured, and the other 2 each had a single small granuloma in the liver, from which *M. bovis* was not isolated. The 3rd founder animal (Y45) had much more extensive lesions that included numerous tuberculoid granulomas throughout the lungs, as well as in the pleura, prefemoral, popliteal, bronchial, and mediastinal lymph nodes, as well as within the periumbilical tissue (Figure 1). The periumbilical lesion is most interesting because it suggests an undetected calfhood mycobacterial omphalophlebitis, most likely acquired prior to capture.

Other factors that support founder Y45 as being the source of tuberculosis in the herd include her advanced state of disease, indicating long-standing infection, and the fact that she was the only animal in the entire herd with significant pulmonary lesions (note that bison O28, who was born in captivity, had a focal, microscopic lesion consistent with tuberculosis in the right caudal lung lobe). In cattle and bison, it is thought that respiratory transmission is the most significant route of spread of *M. bovis* between animals, and that individuals with pulmonary tuberculosis are the primary source of disease within a herd (17,30,31). Since Y45 was the only bison in the herd with wide-spread *M. bovis* lung lesions, she was the most likely source of infection for the other bison. Additionally, 1 affected pre-femoral lymph node in Y45 was draining to the exterior, and might have been an additional source of the bacterium.

Herd records confirmed that all *M. bovis* culture-positive bison, as well as the 2 culture-negative bison with microscopic lesions consistent with tuberculosis, had shared a pen with Y45 for some time during the project, particularly during the later years of herd development. It is interesting to note that although Y45 was likely infected with *M. bovis* in the neonatal period, was incorporated into the breeding herd as a calf, and had close contact with a number of bison over the course of her life, the tuberculosis outbreak did not appear to occur until 9 y into the project, in 2005, the year she herself was culled. Between 2002 and 2005 at least 39 animals were culled and underwent postmortem examination (including necropsy, histopathology, and culture for *M. bovis*) as part of routine herd management and tuberculosis surveillance. *Mycobacterium bovis* was not detected in any of these animals. This suggests that, although Y45 may have been infected with *M. bovis* at capture, her infection was latent during the early years of the project. Latency of several years duration is not uncommon in cases of bovine tuberculosis (13,14), which presents a major problem for disease detection and management. While long-term antimicrobial therapy has been beneficial for the management of tuberculosis in valuable wildlife species (32,33), viable mycobacteria can persist in the face of treatment (32), possibly due to the poor efficacy of antituberculosis medications, such as isoniazid, against the slowly replicating bacilli commonly present in tuberculosis lesions (34). Additionally, prolonged therapy with anti-mycobacterial drugs, similar to what was implemented for the wild-caught bison calves in this project (1), has been shown to produce latency in animals and humans (34–36). Subsequent reactivation of infection and disease progression later in life may have been associated with an event that compromised immune response, such as pregnancy or parturition (13). Y45 was known to have had at least 4 calves between 1999 and 2005 (although none of her calves became infected).

It should be noted that, despite an aggressive antemortem tuberculosis testing regimen, the accidental detection of tuberculosis in bull O28 was the first indication that this disease was present in the herd. The generally poor detection of *M. bovis* infected bison in this herd using antemortem tuberculosis tests is the subject of a separate paper.

From a disease perspective, wood bison conservation efforts in Canada are currently focused on monitoring for *M. bovis* infection in tuberculosis-free wild herds, as well as assessing and controlling the risk of spread of the disease from infected populations. There are currently no plans to attempt further salvage of breeding stock from infected herds through the capture of live animals. However, information generated by the Hook

Lake Project has provided valuable insight into some of the difficulties associated with salvaging tuberculosis-free animals from endemically infected herds, including the possibility of latent infection, the persistence of the bacteria throughout the life of a host, and the inconsistent performance of anti-mycobacterial chemotherapy and antemortem tuberculosis diagnostic tests.

Acknowledgments

The authors thank the CFIA Mycobacterial Diseases Centre of Expertise, Ottawa, Ontario, for materials and expertise. We also thank CFIA field and program veterinarians and inspectors (K. Howden, K. Phillips, B. Keffen, J. Manns) and wildlife pathologists from the Western College of Veterinary Medicine (C. Sangster, J. Linsjo), who played a significant role in the field epidemiological investigation of the outbreak. Funding and coordination of the Hook Lake Project and the investigation was provided by the Government of the Northwest Territories, the Deninu Kue First Nation, and the Ft. Resolution Aboriginal Harvesters Committee. The authors particularly acknowledge the critical contribution of the project operational staff (T. Ellsworth, S. Beck, K. Delorme, L. Jones) who managed the herd and facilitated all field testing. CVJ

References

1. Nishi JS, Elkin BT, Ellsworth TR. The Hook Lake Wood Bison Recovery Project: Can a disease-free captive wood bison recovery herd be recovered from a wild population infected with bovine tuberculosis and brucellosis? Ann N Y Acad Sci 2002;969:229–235.
2. Nishi JS, Stephen C, Elkin BT. Implications of agricultural and wildlife policy on management and eradication of bovine tuberculosis and brucellosis in free-ranging wood bison of northern Canada. Ann N Y Acad Sci 2002;969:236–244.
3. Fuller WA. Canada and the "buffalo," *Bison bison*: A tale of two herds. Canadian Field-Naturalist 2002;116:141–159.
4. Gates CC, Elkin BT, Beaulieu DC. Initial results of an attempt to eradicate bovine tuberculosis and brucellosis from a wood bison herd in northern Canada. Proceedings from the International Symposium on Bison Ecology and Management in North America 1998:221–228.
5. Wilson GA, Nishi JS, Elkin BT, Strobeck C. Effects of a recent founding event and intrinsic population dynamics on genetic diversity in an ungulate population. Conserv Genet 2006;6:905–916.
6. Stemshorn BW, Forbes LB, Eaglesome MD, Nielsen KH, Robertson FJ, Samagh BS. A comparison of standard serological tests for the diagnosis of bovine brucellosis in Canada. Can J Comp Med 1985;49:391–394.
7. Nielsen KH, Kelly L, Gall D, et al. Comparison of enzyme immunoassays for the diagnosis of bovine brucellosis. Prev Vet Med 1996;26:17–32.
8. Gall D, Nielsen K, Forbes L, et al. Validation of the fluorescence polarization assay and comparison to other serological assays for the detection of serum antibodies to *Brucella abortus* in bison. J Wildl Dis 2000;36:469–476.
9. Canadian Food Inspection Agency Disease Control Manual of Procedures. Tuberculosis. 1987.
10. Lin M, Sugden EA, Jolley ME, Stilwell K. Modification of the *Mycobacterium bovis* extracellular protein MPB70 with fluorescein for rapid detection of specific serum antibodies by fluorescence polarization. Clin Diagn Lab Immunol 1996;3:438–443.
11. Canadian Food Inspection Agency Animal, Plant, and Food Risk Analysis Network. Risk assessment on bovine tuberculosis and brucellosis in wood bison of the Hook Lake Recovery Project (I28). Nepean, Ontario; 2003 Feb 19.
12. Lutze-Wallace C, Turcotte C, Stevenson DA, et al. Isolation of *Mycobacterium bovis* from a wood bison in a wildlife conservation project in the Northwest Territories. Can Vet J 2006;47:317–318.
13. Caswell JL, Williams KJ. Respiratory system. In: Maxie MG, ed. Jubb, Kennedy, and Palmer's Pathology of Domestic Animals. 5th ed. Edinburgh: Elsevier, 2007:523–654.
14. Cousins DV, Huchzermeyer HFKA, Griffin JFT, et al. Tuberculosis. In: Coetzer JAW, Tustin RC, eds. Infectious Diseases of Livestock. 2nd ed. Cape Town: Oxford University Press South Africa, 2004:1973–1993.
15. Besser RE, Pakiz B, Schulte JM, et al. Risk factors for positive mantoux tuberculin skin tests in children in San Diego, California: Evidence for boosting and possible foodborne transmission. Pediatrics 2001;108:305–310.
16. Morris RS, Pfeiffer DU, Jackson R. The epidemiology of *Mycobacterium bovis* infections. Vet Microbiol 1994;40:153–177.
17. O'Reilly LM, Daborn CJ. The epidemiology of *Mycobacterium bovis* infections in animals and man: A review. Tuber Lung Dis 1995;76 Supplement 1:1–46.
18. Clifton-Hadley RS, Sauter-Louis CM, Lugton IW, Jackson R, Durr PA, Wilesmith JW. *Mycobacterium bovis* infections. In: Williams ES, Barker IK, eds. Infectious Diseases of Wild Mammals. 3rd ed. Ames: Iowa State Univer Pr, 2001:340–361.
19. Tessaro SV. A descriptive and epizootiologial study of brucellosis and tuberculosis in bison in northern Canada. 1988.
20. O'Brien DJ, Schmitt SM, Fitzgerald SD, Berry DE, Hickling GJ. Managing the wildlife reservoir of *Mycobacterium bovis:* The Michigan, USA, experience. Vet Microbiol 2006;112:313–323.
21. Ryan TJ, Livingstone PG, Ramsey DS, et al. Advances in understanding disease epidemiology and implications for control and eradication of tuberculosis in livestock: the experience from New Zealand. Vet Microbiol 2006;112:211–219.
22. O'Brien DJ, Schmitt SM, Fierke JS, et al. Epidemiology of *Mycobacterium bovis* in free-ranging white-tailed deer, Michigan, USA, 1995–2000. Prev Vet Med 2002;54:47–63.
23. Lugton IW, Wobeser G, Morris RS, Caley P. Epidemiology of *Mycobacterium bovis* infection in feral ferrets *(Mustela furo)* in New Zealand II: Routes of infection and excretion. N Z Vet J 1997;45:151–157.
24. Ragg JR, Mackintosh CG, Moller H. The scavenging behaviour of ferrets *(Mustela furo)*, feral cats *(Felis domesticus)*, possums *(Trichosurus vulpecula)*, hedgehogs *(Erinaceus europaeus)* and harrier hawks *(Circus approximans)* on pastoral farmland in New Zealand: Implications for bovine tuberculosis transmission. N Z Vet J 2000;48:166–175.
25. Delahay RJ, Smith GC, Barlow AM, et al. Bovine tuberculosis infection in wild mammals in the South-West region of England: A survey of prevalence and a semi-quantitative assessment of the relative risks to cattle. Vet J 2007;173:287–301.
26. Wobeser G. Involvement of small wild mammals in bovine tuberculosis. Otago Conference Series 2008;3:267–269.
27. King CM. *Mustela erminea.* Mammalian Species 1983;195:1–8.
28. Sheffield SR, King CM. *Mustela nivalis.* Mammalian Species 1994;454:1–10.
29. Clarke KA, Fitzgerald SD, Zwick LS, et al. Experimental inoculation of meadow voles *(Microtus pennsylvanicus)*, house mice *(Mus musculus)*, and Norway rats *(Rattus norvegicus)* with *Mycobacterium bovis*. J Wildl Dis 2007;43:353–365.
30. Menzies FD, Neill SD. Cattle-to-cattle transmission of bovine tuberculosis. Vet J 2000;160:92–106.
31. Tessaro SV, Forbes LB, Turcotte C. A survey of brucellosis and tuberculosis in bison in and around Wood Buffalo National Park, Canada. Can Vet J 1990;31:174–180.
32. Rietkerk FE, Griffin FT, Wood B, et al. Treatment of bovine tuberculosis in an arabian oryx *(Oryx leucoryx)*. J Zoo Wildl Med 1993;24:523–527.
33. Mikota SK, Peddie L, Peddie J, et al. Epidemiology and diagnosis of *Mycobacterium tuberculosis* in captive Asian elephants *(Elephas maximus)*. J Zoo Wildl Med 2001;32:1–16.
34. Gomez JE, McKinney JD. *M. tuberculosis* persistence, latency, and drug tolerance. Tuberculosis 2004;84:29–44.
35. Manabe YC, Kesavan AK, Lopez-Molina J, et al. The aerosol rabbit model of TB latency, reactivation and immune reconstitution inflammatory syndrome. Tuberculosis 2008;88:187–196.
36. Scanga CA, Mohan VP, Joseph H, Yu K, Chan J, Flynn JL. Reactivation of latent tuberculosis: Variations on the Cornell murine model. Infect Immun 1999;67:4531–4538.